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Response of Navel Lane Late citrus trees to regulated deficit irrigation: yield components and fruit composition

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Abstract The effects of mid-summer regulated deficit irrigation (RDI) treatments were investigated on Navel Lane Late citrus trees over four seasons. Water restrictions applied from July until mid-September were compared with irrigation at full crop evapotranspiration (ETc). Two degrees of water restrictions were imposed: (1) RDI-1, irrigated at around 50% ETc and, (2) RDI-2, irrigated at 30–40% ETc. In addition, threshold values of midday stem water potential (Ψs) of -1.3 to -1.5 MPa for RDI-1 and of -1.5 to -1.7 MPa for RDI-2 were also taken into account. Results showed that Navel Lane Late is a citrus cultivar sensitive to water deficit since both RDI strategies reduced fruit size every year and water use efficiency in RDI trees was similar to control trees. However, the RDI-1 strategy allowed water savings up to 19% without reduction in yield when the water stress integral did not surpass 70 MPa day. RDI improved fruit quality, increasing total soluble solids and titratable acidity, while the fruit maturity was delayed. In conclusion, we suggest that RDI-1 strategy since it did not significantly impair the economic return can be applied in commercial orchards in case of water scarcity. Nevertheless, Navel Lane Late fruit is sensitive to water deficit and the fruit weight can be detrimentally affected.

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Introduction

The competition for scarce water resources has increased in many world regions due to the population growth, economic development and environmental concerns. It is anticipated that irrigation water demand will continue to increase in the foreseeable future (Fereres and González-Dugo 2009). Under such situations, farmers often receive water allocations below the maximum crop evapotranspiration needs (ETc) and either have to concentrate the supply over a smaller land area or have to irrigate the total area with levels below full ETc (Fereres and Soriano 2007). It is important, therefore, to make an effort to increase the efficiency of water use in irrigation.

Regulated deficit irrigation (RDI) is one of the irrigation strategies that has been studied in a wide number of crops (Ruiz Sánchez et al. 2010), and it is known that in many cases, it can allow important water savings without reducing yield. RDI is based on the imposition of water restrictions at certain developmental periods when fruit growth is less sensitive to soil water deficit while full tree water requirements are applied during the rest of the season. Nevertheless, crop response to RDI is very dependent on the timing and severity of the water deficits, and there are significant differences among species (Fereres and Soriano 2007).

In Spain, citrus is one of the most important crops with more than 314.000 ha, of which around 292.000 ha are irrigated. In 2008, the average annual production was six million tons, 53% of which were sweet oranges (MARM 2009). In citrus, it has been demonstrated that even moderate water stress applied during phase I (i.e., flowering and fruit set) normally compromises yield by increasing June fruit drop (Doorenbos and Kassam 1979; Ginestar and Castel 1996; Romero et al. 2006; García-Tejero et al.

2010). On the other hand, water restrictions applied during the last phase of fruit growth and ripening might decrease yield by reducing the final fruit weight (González-Altozano and Castel 1999; Pérez-Pérez et al. 2009; García-Tejero et al. 2010).

González-Altozano and Castel (1999) in experimental orchards planted with Clementina de Nules, and more recently Ballester et al. (2011) in a commercial one, determined that moderate water restrictions (i.e., replacing only 50% of ETc) during July and August successfully allowed reducing water application without any yield or fruit size reductions. They identified a threshold value of plant water stress determined by the measurement of midday stem water potential (Ψs) of around −1.3 to −1.5 MPa.

The aim of this experiment was to assess the application of summer RDI strategies in a commercial grove of Navel Lane Late testing the plant water stress threshold values suitable for Clementina de Nules to avoid the occurrence of severe water restrictions. The overall goal is to provide growers with more reliable information on the use of RDI for optimizing water management in a late-season-maturing orange cultivar.

Materials and methods

Experimental plot and irrigation treatments

The experiment was performed during four consecutive seasons (2007–2010) in a 1.6-ha commercial citrus orchard located in Chulilla, Valencia, Spain (39°40′N, 0°50′W). At the beginning of the experiment, trees were 7 years old. Plant material used was the cv. Navel Lane Late (*Citrus sinensis* (L) Osbeck) grafted on Carrizo citrange (*Citrus sinensis*, Osb. × *Poncirus Trifoliata*, Raf). The orchard was planted at a spacing of 6 m × 4 m. The soil was clay to clay loam texture, rich in calcium carbonate and with 11% by weight stones. The irrigation water was of medium salinity, EC at 25°C of 1.22 dS m^{-1} and of alkaline reaction, pH 7.61.

Prior to the experiment, the orchard was irrigated via surface irrigation. In the spring of 2007, the irrigation system was changed to drip irrigation and adapted to allow the application of different treatments. Thus, during the experiment, trees were drip-irrigated with 8 emitters per tree, each delivering 4 l h^{-1} located on a double line separated 1 m at each side from the trees' line.

The mean annual amount of fertilizers applied through the irrigation system to each irrigation treatment was 104, 32 and 80 kg ha^{-1} of N, P$_2$O$_5$ and K$_2$O, respectively. These amounts were evenly distributed in weekly applications from March to September.

Irrigation scheduling was based on estimated ETc (ETc = ETo * Kc). Reference evapotranspiration, ETo, was calculated by Penman–Monteith formulation from weather information obtained in an automated meteorological station located 4 km from the orchard. The crop coefficient (Kc) varied among months depending on the crop phenological stage. Spring flush growth for Navel Lane Late in this region usually occurs during March, flowering by early May, the physiological fruit drop by early July and harvest from late February to mid-April depending on the market's requirement. At the beginning of the experiment, average tree ground cover was 27% of the soil allotted per tree and the corresponding seasonal Kc, according to Castel (2000), was 0.42. Along the season, Kc values for each month from March to October were respectively 0.41, 0.38, 0.34, 0.38, 0.42, 0.49, 0.46 and 0.52. During the warmest part of the season, drip irrigation was applied daily, and it was controlled and adjusted weekly according to the estimated ETc. Rainfall and ETo during the experimental period are reported in Table 1.

Three irrigation treatments were applied: (1) control, irrigated during the whole season at 100% ETc; (2) moderate deficit irrigation (RDI-1), irrigated at around 50% of the control treatment since the end of the physiological fruit drop (i.e., mid-July) until September 20 (DOY 180–263), September 26 (DOY 196–270), September 29 (DOY 201–272) and September 14 (DOY 201–267) in 2007, 2008, 2009 and 2010, respectively. In addition, deficit irrigation was scheduled in order to avoid that midday stem water potential (Ψs) went below −1.3 to −1.5 MPa, a threshold value previously identified for avoiding fruit size reductions in "Clementina de Nules" (González-Altozano and Castel 1999); (3) severe deficit irrigation (RDI-2), irrigated at 30–40% of the control during the same period as RDI-1 and with a threshold Ψs value of −1.5 to −1.7 MPa. When the Ψs went below the threshold values mentioned, the irrigation was modified in the next week by about +25%. During the rest of the season, both RDI treatments were irrigated as the control.

The statistical design was a randomized complete block with four replicates per treatment. Each experimental unit had three rows with twelve to twenty trees per row. Perimeter trees were used as guard, leaving at least ten sampling trees per plot.

Plant water status

During the RDI application period, stem water potential was measured weekly at solar midday with two pressure chambers (Model 600 Pressure Chamber, PMS Instrument Company, Albany, USA), following procedures described by Turner (1981). Determinations were carried out in mature leaves, bagged in plastic bags and covered with

Table 1 Annual reference evapotranspiration (ETo), rainfall and irrigation for the different years

Year	ETo (mm)	Rainfall (mm)	Control (mm)	RDI-1 (mm)	RDI-2 (mm)
2007	1,143	581	295	206 (30)	182 (38)
2008	1,186	614	343	282 (18)	278 (19)
2009	1,341	342	472	383 (19)	368 (22)
2010	1,214	469	517	456 (12)	435 (16)
2007–2010	1,221	506	407	332 (18)	316 (22)

Irrigation volumes applied with (%) savings in parentheses compared to the "100" treatment are also shown. Defined as: (1 − (irrigation in the "RDI" treatment/irrigation in the control)) × 100

silver foil at least 1 h prior to measurements. A total of 8 trees per treatment and two leaves per tree were monitored with Ψs readings. Water stress integral (S_ψ) was calculated from the midday stem water potential according to the modified equation proposed by Myers (1988):

$$S_\psi = \left| \sum_{i=0}^{i=t} (\overline{\psi}_{i,i+1} - c)n \right|$$

where $\psi_{i,i+1}$ is the mean Ψs for any interval i, $i+1$, c is the maximum Ψs (−0.3 MPa) and n is the number of days in the interval.

Trunk growth, yield and fruit quality

Tree vegetative growth was determined by measuring at the beginning and at the end of each season the trunk perimeter with a metric tape. The measurements were taken at marked sections located about 0.05 m above the graft union and approximately 0.25 m above the ground in all sampling trees of each treatment.

Yield and number of fruit per tree were determined at the time of commercial harvest. Average fruit weight was determined using a commercial grading machine (Polyfruit electronic sizer, Food Machinery Española, S.A., Valencia, Spain). Harvest was carried out in February in 2007 and April in 2008, 2009 and 2010. Water use efficiency (WUE) was calculated as yield divided by irrigation applied plus effective rainfall. Each season, economic returns were calculated considering the relative weight of fruits and the prices received by growers for each commercial category set by the cooperative of the area. Water productivity was calculated according to Fereres and Soriano (2007) as the economic return divided by irrigation applied plus effective rainfall.

At harvest, a sample of 50 fruits per experimental unit (four independent samples per treatment) was collected randomly from selected trees where yield was concurrently measured. A subsample of 25 fruits was used to determine fruit quality at harvest time, while the other 25 fruits were stored at 4°C and 82% RH for 25 days to determine fruit composition after a cold storage period (post-harvest samples). Fruits were weighed, squeezed with a juice machine (Zumonat, Model C-40, Barcelona, Spain) and filtered. Juice total soluble solids content (TSS) was measured with a temperature-compensated digital refractometer (Atago, Palette PR-101), and juice titratable acidity (TA) was determined by titration with 0.1 N NaOH (Metrohm, 785 DMP Titrino). The maturity index (MI) was expressed as the TSS/TA ratio.

Statistical analysis

The data were analyzed using the SAS statistical package (version 9.0; SAS Institute, Cary, NC). Analysis of multiple regression was performed using the "REG" procedure, while analysis of variance according to the "MIXED" procedure. Means were separated by Dunnett's test and contrast between the RDI levels.

Results

Meteorological conditions and irrigation volume applied

Reference evapotranspiration (ETo) registered during the four growing seasons ranged between 1,143 and 1,341 mm (Table 1). Year 2008 was the rainiest with 614 mm of seasonal precipitation, while 2009 was the driest with 342 mm. The air temperature and vapor pressure deficit for each experimental season during the RDI period (July, August and September) are shown in Fig. 1.

The water savings achieved in the RDI treatments for each of the 4 years of study were respectively 30, 18, 19 and 12% in the RDI-1 and 38, 19, 22 and 16% in the RDI-2.

Plant water status

The Ψs values registered in trees from control treatment were quite similar during the 4 years of study with an average value pooled over seasons of −0.91 ± 0.24 MPa (Fig. 2). During the water restriction period, trees from

Fig. 1 Evolution of air temperature (Ta) and vapor pressure deficit (VPD) during the months in which water restrictions were applied for 2007 (**a**), 2008 (**b**), 2009 (**c**) and 2010 (**d**)
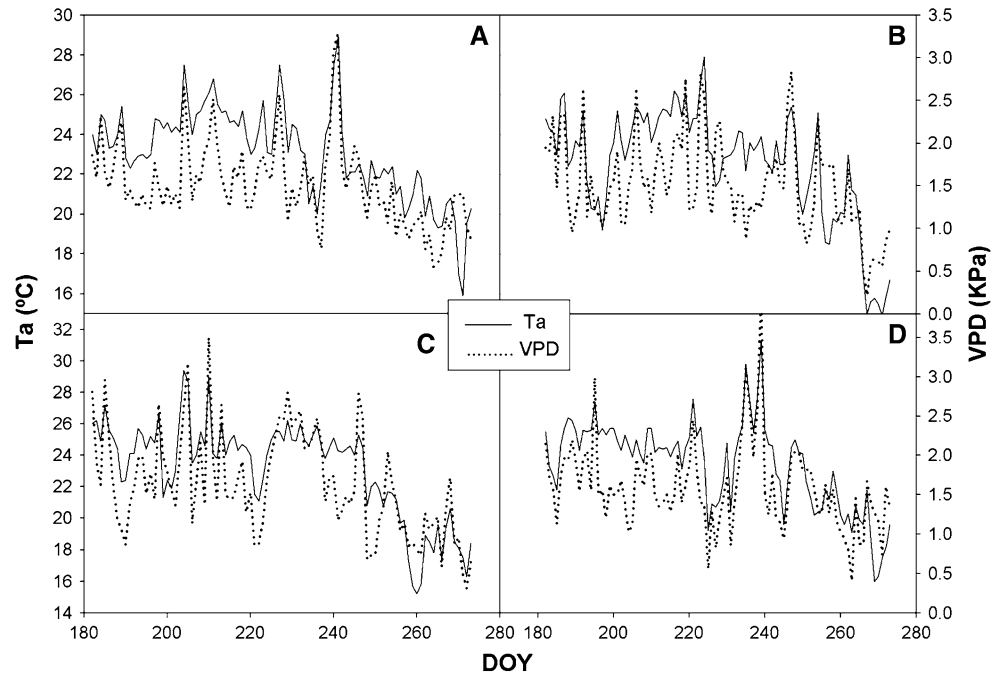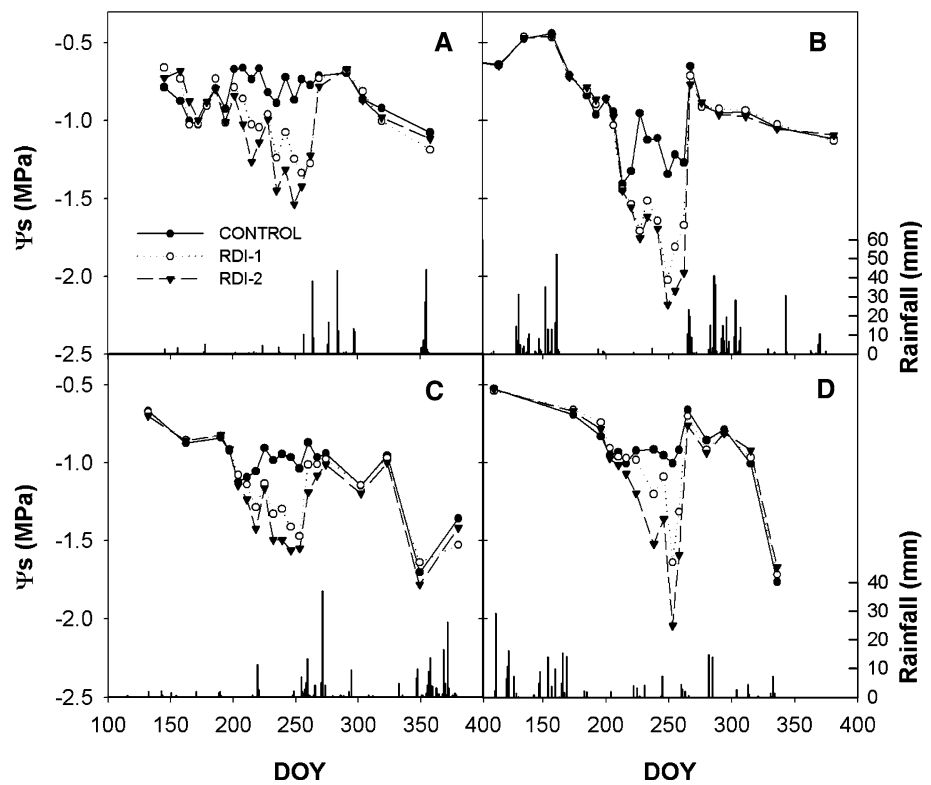

Fig. 2 Seasonal variation of midday stem water potential (Ψs) during 2007 (**a**), 2008 (**b**), 2009 (**c**) and 2010 (**d**). Rainfall events are shown as *vertical bars* originating from the *x* axis

both RDI treatments showed Ψs values more negative than the control ones. For the RDI-1 treatment, average Ψs values were of −1.05 MPa in 2007, −1.45 in 2008, −1.22 in 2009 and −1.13 in 2010. The corresponding S_ψ values reached for each season in the RDI-1 treatment were 66.1, 88.0, 64.2 and 46.7 MPa day, respectively. The RDI-2 trees with more severe water restrictions showed the lowest

Ψs values. On average, for the complete water restriction period of each season, these values were −1.17 MPa in 2007, −1.54 in 2008, −1.33 in 2009 and −1.35 in 2010. The S_ψ values reached for each season in this case were 75.8, 94.3, 78.9 and 59.3 MPa day, respectively.

There was some general variation in plant water status among seasons (Fig. 2). The lowest Ψs values were in

Table 2 Effect of deficit irrigation on fruit number per tree, yield, fruit fresh weight and water use efficiency (WUE) at harvest

Year	Control	RDI-1	RDI-2
No. of fruits per tree			
2007	287	281	262
2008	568	535	542
2009	439	471	452
2010	462	533	510
2007–2010	442	454	454
Yield ($t\ ha^{-1}$)			
2007	30.9	26.2*	25.2*
2008	47.0	36.3*	35.4*
2009	37.9	37.1	34.6*
2010	44.5	42.2	39.0
2007–2010	40.0	36.1	33.9*
Fruit fresh weight (g)			
2007	255	234*	230*
2008	214	184*	178*
2009	253	239	223***
2010	261	234***	225***[y]
2007–2010	246	223***	214***
WUE ($kg\ m^{-3}$)			
2007	3.5	3.3	3.3
2008	4.9	4.1	4.0
2009	4.7	5.1	4.9
2010	3.9	3.9	3.7
2007–2010	4.4	4.4	4.2

*, *** Significant differences at $P < 0.05$ and $P < 0.001$ with respect to control by Dunnett's test. [y] Significant differences at $P < 0.05$ with respect to RDI-1

general recorded in 2008, and even in the control trees, Ψs reached values near -1.5 MPa due to some failure in the irrigation system supply that prevented the irrigation during a couple of days.

Yield and water use efficiency

Yield and its components were markedly different among years, and the statistical significance of the "year" effect from ANOVA was highly significant ($P < 0.01$). On the other hand, the effects of the RDI treatments on yield varied among seasons. In 2007 and 2008, both RDI treatments reduced significantly yield and fruit weight with respect to the control (Table 2). In 2009, water savings of 19% in the RDI-1 treatment (Table 1) did not reduce yield nor fruit weight with respect to the control. Nevertheless, 22% of water savings in the RDI-2 treatment reduced significantly both parameters (Table 2). In the last experimental season, water savings of 12 and 16% in the RDI-1 and RDI-2 treatments, respectively (Table 1), did not

significantly reduce yield respect to the control although the fruit weight was negatively affected (Table 2). RDI treatments shifted the fruit size distribution in all seasons toward smaller fruit size (Fig. 3).

Pooled over seasons, fruit weight was reduced in both RDI levels with respect to the control (9% in RDI-1 and 13% in RDI-2). Although this fruit weight reduction was not sufficient to significantly impair yield in the RDI-1 treatment, it did reduce yield by a significant 15% with respect to the control in the RDI-2 treatment (Table 2).

There were significant correlations between the average fruit weight and both S_ψ and number of fruits per tree (Fig. 4). The analysis of multiple regression showed that S_ψ explained about 34% of the observed variability in fruit weight ($r^2 = 0.34***$), and an additional 24% was due to the number of fruits ($r^2 = 0.24***$).

When the RDI treatments impaired yield, there was a trend to lower water use efficiency in the RDI trees than in control ones albeit without significant differences ($P < 0.05$) in any case (Table 2).

Fruit quality

Titratable acidity varied among years, with a statistically significant effect ($P < 0.05$) of the "year" effect from ANOVA. Deficit irrigated treatments increased fruit TSS and TA at harvest every season with significant differences every year except in 2010 (Table 3). This increase was generally proportional to the intensity of the water stress applied, showing the highest values in RDI-2 treatment. In season 2009, deficit irrigation led to the highest increase in TSS with respect to the control, while the largest increase in TA was in 2007, the year when the RDI period lasted longer. The maturity index was significantly reduced with respect to the control by both RDI treatments every season with the exception of the RDI-1 treatment in 2010. These effects of RDI on fruit composition were also observed in the post-harvest samples that were maintained during 25 days in cold storage (Table 3).

Trunk growth

When the experiment started, the average value for the trunk perimeter of all the sampling trees was 32.1 ± 2.5 cm. RDI treatments reduced trunk perimeter growth (Table 4). Over the 4 years of the experiment, the accumulated relative trunk perimeter growth was 39.6, 30.1 and 29.5% for the control, RDI-1 and RDI-2 treatment, respectively. However, these differences were not statistically significant ($P < 0.05$) due to the large variability in trunk growth within trees as indicated by the coefficient of variation (30%).

Fig. 3 Effect of deficit irrigation on fruit diameter distribution in commercial categories for 2007 (**a**), 2008 (**b**), 2009 (**c**) and 2010 (**d**). ***, ** and * denote significant differences at $P < 0.001$, 0.01 and 0.05, respectively, and ns denotes nonsignificant differences by Dunnett's test. For each category, the *top* asterisks or ns indicates differences between control and RDI-1; the *middle* ones, between control and RDI-2; and the *bottom* ones, between RDI-1 and RDC-2
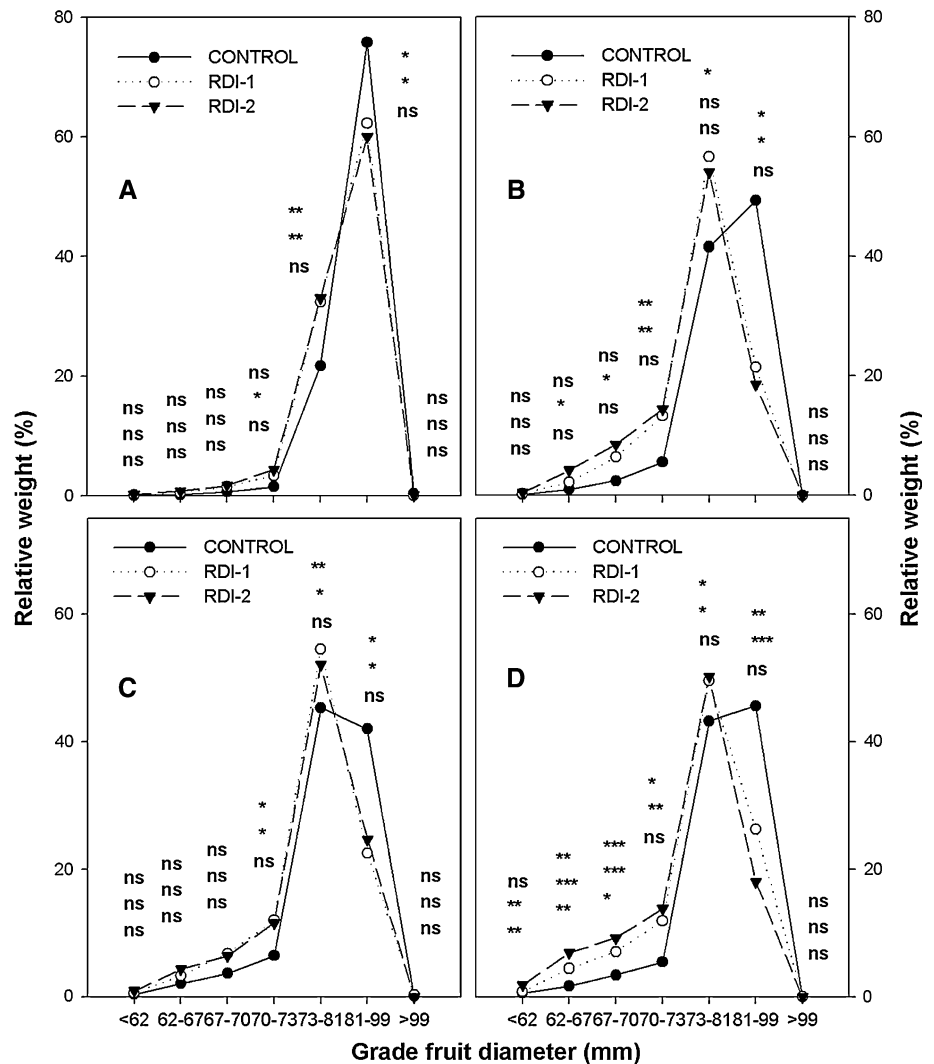
Economic return and water productivity

The moderate RDI level (RDI-1) significantly reduced the economic return the first and second experimental seasons (Table 5) when yield was impaired but did not show differences in 2009 and 2010 nor pooled over the seasons. Nevertheless, the higher plant water stress that occurred in the RDI-2 treatment (Fig. 2) resulted in a significantly smaller economic return every year (Table 5). Over the four seasons, the average reduction in economic return of this RDI-2 treatment was 22% with respect to the control. Both RDI treatments showed similar water productivity values than control trees in 2007, 2009 and 2010. In 2008, water productivity was clearly reduced in both RDI treatments although with significant differences only in the RDI-2 (Table 5). Both the economic return and the water productivity were significantly different ($P < 0.05$) among years.

Discussion

The present experiment was designed in order to corroborate whether previous findings obtained in Clementina de Nules citrus trees (González-Altozano and Castel 1999; Ballester et al. 2011) could be extrapolated to Navel Lane Late, which is a late-season-maturing orange cultivar. Ballester et al. (2011) showed that an irrigation strategy identical to the RDI-1 of the present experiment allowed for 20% water savings without any significant reduction in yield, fruit size or in the economic return in Clementina de Nules. This was not the case for the cultivar Navel Lane Late where even the mild RDI treatment led to a statistically significant reduction in fruit weight (−9% for the average of the 4 seasons) though it did not reduce yield (Table 2). This is somewhat surprising considering that Navel Lane Late is a late-ripening variety and therefore its fruits had more time than the Clementina de Nules

(harvested in December) for a possible compensation in fruit growth after reirrigation to full dosage, as observed in grapefruit by Cohen and Goell (1988) and in Clementina by González-Altozano and Castel (2000). The reasons for this lack of compensatory fruit growth and apparent higher sensitivity to water stress of the NLL cultivar are not completely clear. This could perhaps be due to the fact that
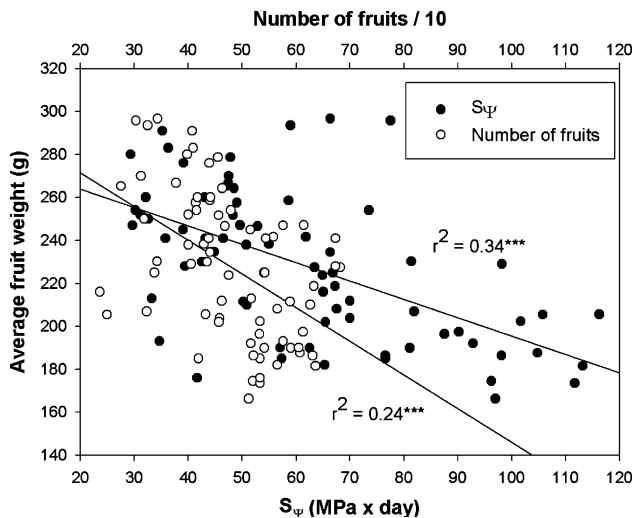

Fig. 4 Relationships among the average fruit weight and the water stress integral (S_ψ) and number of fruits per tree. The equation obtained from the analysis of multiple regression was: $y = 342.5 - 0.78S_\psi - 0.14Nf$, $r^2 = 0.52***$. Each value is a single measurement per tree ($n = 72$). The period length used to calculate the S_ψ varied between 56 and 88 days for the different years depending on the duration of the water stress period

Table 4 Effect of deficit irrigation on relative trunk perimeter growth

Year	Control	RDI-1	RDI-2
Relative trunk growth (%)			
2007	13.1	9.7*	11.0
2008	7.1	6.0	6.2
2009	7.0	6.0	5.7
2010	6.7	6.3	6.1*
2007–2010	39.6	30.1	29.5

* Significant differences at $P < 0.05$ with respect to control by Dunnett's test

Table 5 Effect of deficit irrigation on economic return and water productivity

Year	Control	RDI-1	RDI-2
Economic return (€ tree^{-1})			
2007	26.1	22.2*	21.2*
2008	29.5	21.0*	20.4*
2009	26.2	24.6	23.3*
2010	31.6	28.0	24.6*
2007–2010	28.4	24.2	22.1*
Water productivity (€ m^{-3})			
2007	1.24	1.18	1.16
2008	1.28	0.98	0.95*
2009	1.34	1.41	1.37
2010	1.16	1.09	0.98
2007–2010	1.26	1.16	1.11

* Significant differences at $P < 0.05$ with respect to control by Dunnett's test

Table 3 Effect of deficit irrigation on fruit juice total soluble solids (TSS), titratable acidity (TA) and maturity index (MI) at harvest and after a period of 25 days of cold storage

Year	Harvest				Post-harvest		
	Control	RDI-1	RDI-2		Control	RDI-1	RDI-2
TSS (°Brix)							
2007	11.3	12.2*	11.9		11.3	12.2**	12.3**
2008	11.5	12.3*	12.3*		11.8	12.4*	12.8***
2009	12.2	13.5**	13.6**		–	–	–
2010	10.9	11.2	11.6		11.1	11.7*	12.1***
TA (% citric acid)							
2007	0.86	1.07*	1.10*		1.03	1.24*	1.32**
2008	0.87	0.99**	1.02**		0.87	0.96**	0.99***
2009	0.75	0.91**	0.95***		–	–	–
2010	0.83	0.89	0.95*		0.96	1.15***	1.15***
MI							
2007	13.2	11.5*	10.9*		11.0	10.0	9.5
2008	13.2	12.4*	12.1**		13.7	13.0*	13.1
2009	16.3	14.9**	14.2***		–	–	–
2010	13.2	12.7	12.2*		11.6	10.3**	10.6**

Within rows,*, ** and *** mean significant differences at $P < 0.05$, $P < 0.01$ and $P < 0.001$ with respect to control by Dunnett's test

NLL fruits achieved 81% of its final size at the end of the period of water restrictions when irrigation was resumed to normal dose while Clementina de Nules, for instance, achieves only about 71%. The present results demonstrate that it is not always straightforward to extrapolate RDI results among varieties and that before suggesting the widespread adoption of RDI strategies to commercial situations, local field experiments need to be conducted. Indeed, the significant impair in yield obtained in 2008 suggests that the threshold value of Ψs (-1.3 to -1.5 MPa) suitable for summer RDI strategies in Clementina de Nules (Ballester et al. 2011) is not appropriate for Navel Lane Late. For the application of summer RDI on NLL, we suggest threshold Ψs values of -1.2 to -1.3 MPa. In addition, 70 MPa day is the value that we propose as S_ψ threshold since this was the highest value that we observed in the RDI treatments that did not lead to a reduction in yield.

Results reported indicate that the impact of the RDI treatments imposed on tree yield depend on the duration and degree of severity of the plant water deficit rather than just on the reduction in water application. In fact, similar reductions in water application were obtained in 2008 in both RDI treatments and in 2009 in the RDI-1. Despite this, in 2009 when the water stress integral reached by the RDI-1 treatment was of only 64.2 MPa day, yield was not reduced by the deficit irrigation applied, while in 2008 when the water stress integral was 88.0 and 94.3 MPa day in the RDI-1 and RDI-2 treatments, respectively, yield was significantly lower in the RDI trees than in the control ones. These facts indicate that when deficit irrigation is applied, it is necessary to measure the plant water stress in order to determine the impact that imposed water restriction have on plant water status. In this sense, it can be speculated that in 2008, RDI trees suffered more stress than in 2009 because the tree crop level (i.e., the number of fruits per tree) was higher in 2008 than in 2009. Particularly in stone fruit trees, it has been well documented that tree crop level is a determinant factor affecting plant water status (Naor 2006). In citrus trees, the possible interactive effects between deficit irrigation and tree crop level has not been comprehensively studied, because thinning is not a normal cultural practice. Our results might then indicate that further studies should be conducted to more precisely define the effect of crop level and deficit irrigation in a multiple factor experiment with both factors varying within the same season.

Similarly to other RDI experiments conducted in citrus trees (Hutton et al. 2007; García-Tejero et al. 2010), deficit irrigation applied during the second phase of fruit growth increased fruit TSS and TA. In our experiment, the effects of RDI on fruit TA were more pronounced than those observed for TSS. This fact suggests that plant water stress

led to an increased synthesis of organic acids as an osmotic adjustment mechanism (Yakushiji et al. 1996; Hockema and Etxeberria 2001; Barry et al. 2004) rather than a concentration effect due to smaller fruits. Apart from the physiological reasons for this higher increase in TA than in TSS brought about by water stress, this fact caused a decrease in the maturity index for the RDI treatments. This can be considered as a positive outcome since a delay in fruit ripening has commercial advantages in late-season-maturing cultivars that often increase in market price when they are picked later in the season. Previous studies on Clementina de Nules have also reported this drop of the MI in deficit irrigated trees when irrigation was withheld from mid-June to early October (Navarro 2008). However, this effect was not observed when trees were irrigated at 30–40% of ETc from July to mid-September (Ballester et al. 2011). This different behavior of MI in response to RDI treatments suggests that it may depend on the intensity of the stress reached by trees.

The growth reduction in RDI trees can be considered also a positive effect since it diminishes the competition between vegetative and reproductive growth, increasing tree efficiency. Moreover, as other studies in Navel Lane Late have reported (Pérez-Pérez et al. 2010), this growth reduction can suppose an important diminution in the variable and fixed operating costs associated with the crop management as pruning or water and energy for pumping. The reduction in these costs could compensate in some instances the possible profit reduction due to the smaller fruit size.

Conclusions

Moderate water restrictions during summer can be then applied in commercial orchards in case of water scarcity, allowing water savings up to 19% without significant reductions in yield or in the economic return. Even after four consecutive seasons of deficit irrigation application, tree's bearing capacity was not impaired. This was probably because water restrictions were applied after the end of June fruit drop and water stress did not modify vegetative and reproductive growth flushes. Nevertheless, Navel Lane Late fruit size can be reduced even with water savings of 12%, so plant water status will need to be frequently monitored to avoid an excessive reduction in fruit weight, which could impair significantly the yield value when markets require large fruit weights.

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